# R E S E R V O I R   R E G U L A T I O N   M A N U A L

FOR

ALAMO RESERVOIR

COLORADO RIVER BASIN, BILL WILLIAMS RIVER, ARIZ.

## AUTHORITY

1. The authority for preparation of this manual is contained in paragraph 5, Engineer Regulation 1110-2-240, titled "Engineering and Design, Reservoir Regulation," dated 22 April 1970. Detailed requirements for the contents of the manual are contained in Chapter 6, Engineer Manual 1110-2-3600, titled "Engineering and Design, Reservoir Regulation," dated 25 May 1959.

## SCOPE

2. This manual contains (a) general descriptive information pertaining to the drainage area and project; (b) a description of the plan of operation and its application to various floods; (c) the District's organization for operations; and (d) sources of hydrologic data.

## BASIN INFORMATION

3. Description.--Alamo Reservoir is on the Bill Williams River, 39 miles upstream from its confluence with the Colorado River in Havasu Lake. The dam is on the border of Yuma and Mohave Counties, Arizona, about 2.5 miles downstream from Alamo Crossing. Location of the project is shown on plate 1. Main access is from the town of Wenden, on U.S. Highway 60 and 70, approximately 36 miles south of the reservoir. The paved access road from Wenden, improved as a part of the project, has been transferred to Yuma County for maintenance. The drainage area contains about 4,770 square miles, generally mountainous, in west-central Arizona. This drainage area is bounded on the north by the Cottonwood Cliffs; on the east by the Juniper and Santa Maria Mountains; on the south by the Date Creek and Harcuvar Mountains; and on the west by the Hualpai Mountains.

4. The Bill Williams River is formed about 47 miles upstream from its mouth by the confluence of the Big Sandy and Santa Maria Rivers. From the confluence, the flow is southwest for about 8 miles on an average gradient of 18 feet per mile to Alamo Reservoir. Bullard Wash is the

largest tributary along this reach. Below Alamo Reservoir, the river flows almost due west to the Colorado River.

5. The Big Sandy River, larger of the two main tributaries, drains an area of about 2,840 square miles. This stream, which is formed by the confluence of Trout and Knight Creeks, flows southward about 49 miles on an average stream gradient of 38 feet per mile to the Santa Maria River confluence. Burro Creek is the largest tributary in this reach. 6. The Santa Maria River drains an area of about 1,550 square miles. This stream, which is formed by the confluence of Kirkland and Sycamore Creeks, flows southwestward about 51 miles to its junction with the Big Sandy River. The stream gradient of the Santa Maria River is about 30 feet per mile. Date Creek is the largest tributary in this reach. The streambed gradients of many of the minor upstream tributaries in the Bill Williams River system are more than 100 feet per mile.

7. The drainage area consists essentially of broad desert valleys and irregularly distributed ranges of rugged mountains. Relief is moderately great. Elevations in the drainage area vary from about 990 feet above sea level at the dam to 8,266 feet at Hualpai Peak on the northwest boundary. A topographic map of the area is shown on plate 2. Surface soils in the southern and central parts of the area and in the district along the Big Sandy River vary in texture from fine gravels to clay. Shallow, rocky soils occur in a few small isolated areas near the mountain summits.

8. Vegetation in the drainage area is characteristic of rainfall distribution. Except for small areas at the higher elevations, the density of vegetation is low. Near the summit of the Hualpai Mountains, pine occurs in open woodland, associated with various grasses. Below the pines of the Hualpai, in the northeast part of the drainage area, a piñon-juniper belt extends down to about elevation 5,000 feet. A grassy weed-sod occurs here on level or rolling terrain. Shrubs such as scrub oak and rabbit brush grow in the rough and rocky parts. Below the piñon-juniper zone to about 3,500 feet are two distinct types of cover. The more rugged portions support a chaparral, and a short grass grows on the relatively flat areas. Below 3,500 feet, the vegetation is typically desert, consisting of such plants as creosote bush, various salt bushes, cat's claw, and cactus.

9. Economic development.--Practically all economic development protected by Alamo Dam is along the lower Colorado River; very few improvements are located on the Bill Williams River below the dam. The area that would have been inundated by the reservoir design flood prior to construction of Alamo dam is shown on plate 3. Property of significant value is situated in the lowlands of the Colorado River between Parker Dam and the Mexican border, a distance of about 200 river-miles. The

principal downstream areas are designated as: Parker Dam to Parker, Parker Valley, Palo Verde and Cibola Valleys, and Yuma Valley.

10. The value of the protected areas was estimated in 1961 at $222,000,000. Areas susceptible to damage contain residential, business, and industrial property, and various facilities such as irrigation and flood-control works, highways, and public utilities.

11. The total value of the overflow areas under average future conditions at the end of the period 1962-2061 is estimated at $265,000,000. This is based on 1961 unit prices and the estimated average development over the ensuing 100 years, without considering additional flood-control improvements.

12. Existing structures affecting runoff.--Except for small temporary diversion structures built by farmers, no dams have been constructed in the Bill Williams River basin. There are, therefore, no improvements that have a regulatory effect on flood flows at Alamo Reservoir.

13. Precipitation.--Much precipitation in the drainage area results from general winter storms that are associated with extratropical cyclones of north Pacific origin. These storms, which may cover thousands of square miles, occur during the months November through April and occasionally last 4 days or more. The storm rainfall is usually of comparatively low intensity, and its distribution reflects orographic influence. Storms during the summer rainy season, July through September, are of two types: "general summer storms" and "local summer storms." The latter, which are frequent, may result in heavy rain over small areas, but their duration rarely exceeds 3 hours. The general summer storms, which are infrequent, cover comparatively 'Large areas. They sometimes result in high short-term rainfall intensities. The duration of, these storms may be 24 hours or more.

14. Precipitation records are available for 52 precipitation stations in and near the Bill Williams River drainage area. The longest is for Prescott, which has 64 years of record, 1905-1968. The 90-year mean (1868-1957) seasonal precipitation ranges from about 9 inches at the dam to 22 inches along the crest of the mountains near Prescott (see pl. 4). Climatic conditions in the basin generally vary with elevation. Normally, about one-third of the annual precipitation occurs during July and August, and about one-half in the fall and winter months. Although snow has been recorded throughout the drainage area, it is rare below elevation 2,000 feet. Pertinent data for five selected climatological stations (Alamo No. 1, Bagdad Airport, Kingman, Prescott W.B. Airport, and Seligman) are given in tables 1 through 5, and their locations are shown on plate 1.

15. Runoff.--Rapid concentration of water in the main channel produces runoff characterized by high peaks and channel velocities. Runoff is

relatively high because of a combination of well-entrenched streams having steep gradients, impervious soil formations, fan-shaped collecting systems, and irregular distribution of rainfall. Perennial flow in some reaches of the Bill Williams, Santa Maria, and Big Sandy Rivers results from rising water at subterranean bedrock constructions. Normally, streamflow occurs only during and immediately following major storms, except for occasional snowmelt runoff from headwater areas.

16. Prior to the construction of Alamo Dam, two stream gaging stations existed in the Bill Williams River basin. The "Bill Williams River near Alamo" was located about six miles downstream from the confluence of the Santa Maria and Big Sandy Rivers. The "Santa Maria River near Alamo" was situated on the river about one-half mile upstream from the confluence with the Big Sandy River. Twenty-six miles downstream from the dam a stream gaging station, "Bill Williams River at Planet," was located about one mile west of Planet from 1910 to 1946. Runoff records for these stations are contained in tables 6 through 8.

17. Floods.--Historical accounts indicate that there have been many floods in the drainage basin. Floods with estimated peaks exceeding 100,000 cubic feet per second occurred on the Bill Williams River at Planet in March 1884, February 1891, April 1905, March 1906, December 1906, January 1910, January 1916, and February 1927. The floods of 1891, 1916, and 1927 were outstanding. More recently, floods have occurred in August 1931, February 1932, February 1937, March 1938, September 1939, December 1940, March 1941, August 1951, December 1951, and March 1954. Brief descriptions of two outstanding storms and floods of comparatively recent times, those of February 1937 and September 1939, are given in the following paragraphs.

18. Storm and flood of 6-8 February 1937.--The 6-8 February 1937 storm was caused by an intense low pressure area with an associated complex frontal system, which passed over Arizona and resulted in heavy precipitation on the 7th in central Arizona. The total precipitation at Prescott and at Wikieup was 4.05 and 3.90 inches, respectively. Isohyets of the total storm precipitation are shown on plate 5. The storm produced a peak discharge of 92,500 cubic feet per second on the Bill Williams River at Planet on 7 February (see table 8).

19. Storm and flood of 3-8 September 1939.--Unusually heavy rain fell in the storm of 3-8 September 1939, which covered an area of more than 3,000 square miles east of Needles, California. The storm was associated with three cyclones originating off the west coast of Mexico. Total storm precipitation at Wikieup and Truxton was 7.03 and 6.55 inches, respectively. Isohyets of the total storm precipitation are shown on plate 6.

20. Peak discharges from the 1939 storm were as follows:

| Location | Peak discharge Cubic feet per second | Date |
|---|---|---|
| Big Sandy River near Signal........ | *100,000 | 6 September |
| Santa Maria River near Alamo....... | 22,300 | 6 September |
| Bill Williams River near Alamo..... | 86,000 | 6 September |
| Bill Williams River at Planet...... | 73,000 | 7 September |

21. Flood damages.--Little information is available on flood damages in the Bill Williams River basin. Damages resulting from the storm of September 1939 in the lower Colorado River, including land, buildings, and improvements, were estimated at $50,000. Damages in other floods were estimated at $1,500 in February 1932 and $8,500 in March 1938.

22. Downstream channel.—The existing channel of the Bill Williams River below Alamo Dam is adequate to carry controlled releases of 7,000 cubic feet per second without significant damage. Releases from Alamo Reservoir into the Bill Williams River eventually enter Havasu Lake, which is a part of the lower Colorado River system of reservoirs. Channel capacities and downstream structures from Parker Dam, which impounds Havasu Lake, to the Mexican border are shown on plate 7.

23. The lower Colorado River channel is continually being improved by the Bureau of Reclamation. The Cibola Valley reach is currently being dredged to a capacity of 80,000 cubic feet per second, and future plans include dredging in the lower Parker and Yuma Valleys.

## PROJECT INFORMATION

24. Authorization.--Alamo Reservoir was constructed under authorization of the Flood Control Act of 22 December 1944 (Public Law 534, 78th Cong., 2nd sess.). The project was recommended for approval by the Chief of Engineers in his report dated 11 April 1944, published as a part of the project document (H. Doc. 625, 78th Congress, 2nd sess.).

25. Changes in authorized plan.--Major differences between the final project plan and the plan approved by Congress are given in the following subparagraphs:

a. A rolled earthfill dam with detached spillway was substituted for a concrete arch dam with overflow spillway.

b. The dam was relocated upstream about one mile.

c. Hydroelectric power development was eliminated as a possible project feature.

d. Storage capacity below spillway crest was increased from 946,000 to 1,043,000 acre-feet.

e. Public-access facilities were added to the project.

26. Construction history.--Preliminary construction at Alamo Reservoir began in July 1963. The access road, begun in October 1963, was completed in October 1964. The dam and appurtenant works were started in March 1965 and completed in July 1968.

27. Purpose.--The basic purpose of the project is to provide protection for the valley of the lower Colorado River against floods originating on the Bill Williams River drainage. The project also provides storage for conservation and recreation, and public access thereto.

28. Relationship to coordinated plan of development for the basin.-The operation of Alamo Dam is closely coordinated with the operation of dams on the lower Colorado River. The U.S. Bureau of Reclamation's office in Boulder City, Nevada, is responsible for operation of the lower Colorado River System and for flood protective works on the main stem of the river. All releases from the water conservation and flood control pools in Alamo Reservoir (which enter Havasu Lake) are coordinated with the Bureau of Reclamation to obtain maximum benefits. These benefits include water conservation, power generation, and flood control.

29. The design flood for the Yuma levees, downstream from Laguna Dam, was derived on the basis of a general summer storm under the assumption that the Alamo Dam outlets would be closed during the flood peak at the Yuma levees. Deviation from the fixed operation schedule for flood control would be permitted, to reduce flooding along the Colorado River, especially between Laguna Dam and Mexico.

30. Description. A general plan of the project is shown on plate 8, and a detailed description is contained in the following paragraphs.

31. Dam.--The dam is a zoned earthfill structure with a crest length of 975 feet at top of dam, elevation 1,265 feet, and a crest width of 30 feet. The height above the original Bill Williams River streambed is 283 feet. The downstream slope of the embankment is 1 vertical on 2 horizontal and the upstream slope is 1 on 2.5. Both the upstream and downstream faces of the dam are protected by a layer of stone facing.

A general plan of the embankment is shown on plate 9, with sections shown on plate 10.

32. Outlet works.--The outlet works are in the left, or southeast, abutment of the dam. The concrete-lined outlet tunnel is 1,290 feet long, and is 12 feet in diameter except through the gate conduit section. At the entrance, there is a semicircular grated intake structure, and at the exit an unlined outlet channel. The gate chamber, just upstream from the axis of the dam, is circular in plan, and is 36 feet in diameter. Discharge is controlled by 3 pairs of slide gates 5.5 feet wide by 8.5 feet high, installed in tandem. Gates are hydraulically operated, open or close about one-half foot per minute, and may be locked in any position. A butterfly valve controls outflow through an 18-inch pipe bypassing Gate No. 3, permitting releases of 25 cubic feet per second or less. The water-surface elevation must reach 1,002.3 to initiate bypass operation. Details of the outlet works are shown on plates 11 and 12, and outlet discharge curves are shown on plate 13.

33. A control house is located on top of the dam about the midpoint of the outlet conduit. It contains a hydraulic pump unit and control valve station, water-surface recorder, selsyn gate-position indicators and recorders, radio transceiver, telephone and electric power installations, and sanitary facilities. Information on equipment pertaining to the hydrologic network is contained in a subsequent paragraph titled "Hydrologic facilities."

34. Power service to the control house is provided through underground conduits from the standby generator house about 140 feet away. Commercial 3-phase power at 480 volts and 60 $H_z$, and single phase power at 480 volts and 60 $H_z$ (for lighting service), is supplied to the project. The standby power unit is a 60 kw, 480-volt AC generator with diesel engine, operated from a control panel having transfer switches for commercial or standby power. Fuel for the generator engine is stored in two 275-gallon tanks.

35. The control house is at the head of a shaft connecting with the gate chamber about 262 feet below (see pl. 12). This shaft contains a passenger-freight elevator; emergency ladders; piping for water and high-pressure oil; ducts for ventilation and air venting; and conduits for instrumentation, electric power, and telephone circuits.

36. Spillway.--The detached broadcrested spillway, at crest elevation 1,235 feet, is located in the right abutment (see pl. 9).

a. The spillway channel, an unlined trapezoidal section 110 feet wide by about 500 feet long, cuts through a rock saddle, with the concrete spillway crest block, 3 feet wide by 116 feet long, entrenched in rock. A 12-foot berm is 35 feet above the spillway channel invert on both side slopes. The spillway profile and section are shown on plate 10. The spillway discharge curve is shown on plate 14.

b. Spillway flow discharges into a gully separated from the right abutment by a rock ridge. Flow rejoins the Bill Williams River about 1,500 feet downstream from the toe of the dam. Two sets of ranch buildings would be endangered by impinging spillway flow between Alamo Dam and Havasu Lake, and a third set of buildings by rising water. A high-pressure gas line which crosses the river about 12 miles above Planet would be subject to damage or destruction.

37. Reservoir.--Based on the original survey of March 1963, the reservoir formed by Alamo Dam has an area and gross capacity at spillway crest (elev. 1,235) of 13,300 acres and 1,043,000 acre-feet, respectively. This volume comprises, from the spillway crest down, allocations of 608,000 acre-feet for flood control; 230,000 acre-feet for water conservation; 5,000 acre-feet for recreation; and 200,000 acre-feet for sedimentation. At the top of the dam the area is 17,100 acres and the capacity 1,499,000 acre-feet. Area and capacity curves (containing minor changes resulting from a bottom survey in May 1968) are shown on plate 15 and a tabulation of areas and capacities is given in table 9.

38. Basis for hydrologic design.--The design of Alamo Reservoir was based on sufficient storage capacity to control the reservoir and spillway design floods described in the succeeding subparagraphs, and to provide storage for recreation, water conservation, and sedimentation. Development of the design floods appears in Appendix 2 of General Design Memorandum No. 3 for Alamo Reservoir, dated April 1964.

a. Reservoir design flood.--The reservoir design flood was based on a general winter storm-type. A synthetic storm of 7 days' duration, with daily rainfall increasing gradually to a maximum on the last day, was assumed for design. The maximum 24-hour rainfall averaged 4.25 inches over the drainage area and the storm total 6.84 inches. The total effective rain for the storm was 1.31 inches. It was assumed the water equivalent of snow varied from 0 inches at 4,000 feet elevation to 5 inches at 6,500 feet elevation. Computations by the modified rational method resulted in a peak flow of 317,000 cubic feet per second and a 6-day runoff value of 422,000 acre-feet.

b. Spillway design flood.--The spillway design flood was based on the U.S. Weather Bureau's estimate of probable maximum precipitation, which was derived from a hypothetical tropical storm. This storm was assumed to be of 3 days' duration with average rainfall depths over the drainage area for durations of 3, 12, 24, 48, and 72 hours of 2.2, 5.5, 7.7, 10.2, and 12.0 inches, respectively. Ground conditions conducive to maximum runoff are reflected in the loss rate of 0.25 inch per hour (or 90 percent when precipitation is less than 0.25 inch per hour) assumed to prevail through the entire storm. The assumption was made that the effect of snowmelt would be mostly to condition the ground for maximum runoff. Computation by the unit hydrograph method resulted in a peak flow of 580,000 cubic feet per second and a runoff volume of 893,000 acre-feet for the flood. The unit graph used in developing the spillway design flood is given in table 10.

## BASIS FOR OPERATION

39. Flood-control operation.--The flood-control operation of Alamo Dam is based on controlling the reservoir design and spillway design floods to a downstream discharge of 7,000 cubic feet per second insofar as possible, using the available flood-control space (608,000 acre-feet under net storage conditions). Selection of 7,000 cubic feet per second as the controlled discharge was based on two factors; (a) the channel capacity of the Bill Williams from Alamo Dam to Havasu Lake is ample to carry this discharge without significant damage; and (b) the Colorado River channel capacity below Parker Dam is about 25,000 cubic feet per second. Assuming no side inflow, the maximum release from Lake Mead of about 18,000 cubic feet per second plus the discharge from Alamo reservoir of 7,000 cubic feet per second could be safely passed through Parker Dam.

40. Conservation operation.--The United States Bureau of Reclamation's operation of Havasu Lake is integrated with the operation of Hoover and Davis Dams to effect maximum conservation of flows. The Bureau proposed that 230,000 acre-feet of storage space for water conservation be retained in Alamo Reservoir (see Appendix 3 of General Design Memorandum No. 3 for Alamo Reservoir). Releasing this water at the rate of 2,000 cubic feet per second would increase the water supply in the lower Colorado River system, on the average, by 4,500 acre-feet per year.

41. Recreation operation.--Studies by this office indicate that a 500-acre lake (5,000 acre-feet) would be maintained in Alamo Reservoir 65 percent of the time by storing a maximum of 7,000 acre-feet of water. In these studies, it was assumed that; (a) a ten-year accumulation of sediment existed, (b) a maximum outflow of 10 cubic feet per second was made to satisfy water rights, and (c) the annual evaporation was 66 inches.

42. Water rights operation.--Based on examination of low-flow records for the period 1891 to 1962, it was decided that releasing the reservoir inflow up to a maximum of 10 cubic feet per second would satisfy water rights. Flows during the period studied were generally 1 to 3 cubic feet per second, except during floods.

43. Sedimentation.--The estimate of sediment that would accumulate in Alamo Reservoir is based on recorded data for nearby streams and for existing reservoirs in the general area. The storage space required for a 100-year accumulation, 200,000 acre-feet, was obtained by applying

a sedimentation rate of 0.42 acre-foot per square mile per year to the drainage area of 4,770 square miles. The sediment was assumed to be distributed in proportion to the reservoir area up to the water surface for the reservoir design flood.

44. In order to check sedimentation periodically, six Category "A" index ranges were established in the reservoir area and four Category "C" index ranges along the downstream channel. A reconnaissance survey will be made every two years, or after a major storm, to determine if index ranges should be resurveyed.A comprehensive survey of Alamo Reservoir will be made whenever a survey of the Category "A" ranges indicates an appreciable amount of sediment. At least one such survey will be made every ten years, however. Category "C" ranges will be surveyed at least once every five years. Locations of index ranges are shown on plates 16 and 17.

## OPERATION

45. Design operation plan.--The design operation plan for Alamo Reservoir is presented in the report, "General Design for Alamo Reservoir, Design Memorandum No. 3," dated April 1964. Operation under this plan, as described in the following subparagraphs, accomplishes the objective stated in the section of this manual titled "Basis for Operation." Elevations and storages are based on net storages.

a. Flood-control.--The storage space between elevations 1160.4 and 1235 (spillway crest) amounts to 608,000 acre-feet. A portion of this space is used to control the reservoir design flood to elevation 1215.2 with a maximum discharge of 7,000 cubic feet per second. The remaining flood-control space is used to regulate a flood larger than the reservoir design flood to the same discharge. Above spillway crest, the flow is transferred to the spillway by gradually closing the outlets, until at elevation 1244.5 they would be completely closed and the spillway discharging 7,000 cubic feet per second. Above elevation 1244.5, the outlets are opened as rapidly as necessary to prevent further increase in reservoir stage. During falling stages, the procedure is reversed.

b. Conservation.--The storage space between elevations 1070 and 1160.4 is 230,000 acre-feet. This space is reserved for conservation and releases do not exceed 2,000 cubic feet per second. They are coordinated with the U.S. Bureau of Reclamation to achieve maximum conservation of water in the lower Colorado River.

c. Recreation.--The storage space below elevation 1070, amounting to 5,000 acre-feet, is reserved for a lake with a maximum surface area of 500 acres. During the dry season it may not be possible to maintain a lake of this size, as the inflow could be less than evaporation losses and releases to satisfy water rights.

d. Water rights.--Vested water rights along the downstream channel have not been determined to date. However, a study of past records indicates that releasing the inflow up to a maximum of 10 cubic feet per second would satisfy water rights.

46. Operation plan.--The current operation plan for Alamo Reservoir is similar to the design plan. Differences are due to the use of existing gross storage rather than net storage. An outlet gate operation schedule for the current plan is given in table 11.

a. Flood-control.--In this schedule, the storage space between elevations 1174 and 1235 (spillway crest), amounting to 608,100 acre-feet, is used to control floods to an average maximum discharge of 7,000 cubic feet per second. Above spillway crest, the gates are gradually closed, transferring flow to the spillway until at elevation 1244.5 they are completely closed and the spillway discharging 7,000 cubic feet per second. As the reservoir water surface rises above elevation 1244.5, the gates are opened as rapidly as necessary to prevent further increase in reservoir stage. They are fully open at elevation 1246.5. During falling stages, the gate operation schedule is followed in reverse.

b. Conservation.--The storage space of 427,500 acre-feet between elevations 1046 and 117 is used for conservation. Releases are restricted to a maximum of 2,000 cubic feet per second and the pool is evacuated after each flood. Evaporation is reduced by retaining water in Lake Mead rather than in Alamo Reservoir. Conservation is effected by coordinating Alamo Reservoir releases with releases from Lake Mead and Lake Mohave, on the Colorado River. When 2,000 cubic feet per second is released from Alamo Reservoir, releases from Lake Mohave and Lake Mead can be reduced by 1,700 cubic feet per second. This is the discharge flowing into Havasu Lake after a 15 percent loss between Alamo Dam and Havasu Lake is deducted.

c. Recreation.--The storage space of 9,700 acre-feet between elevations 990 and 1046 is reserved for recreation. Releases are restricted to the inflow, up to a maximum of 10 cubic feet per second, to satisfy water rights.

d. Water rights.--Reservoir operation for water rights under the current plan is the same as under the design plan. The inflow is released up to a maximum of 10 cubic feet per second.

47. Modification of operational plan.--The reservoir regulation plan given in the fixed gate-operation schedule, table 11, serves as a guide for personnel operating Alamo Reservoir during flood conditions. This schedule represents the best method of operation under a given range of predetermined conditions. The fixed schedule is predicated upon the control of floods of a given magnitude and will effect the best overall

control. Temporary deviations from the schedule may be made at any time, especially if flooding is anticipated in the lower Colorado River. The design flood for the Yuma levees, downstream from Laguna Dam, was derived from a general summer storm, assuming the Alamo Dam and Painted Rock Dam outlets closed during the flood peak. Other deviations may be made, based on runoff predictions for the drainage area above the dam, if there is high confidence in the prediction of runoff and future weather conditions. Deviations of this type will seldom be necessary, as Alamo reservoir contains storage space in excess of that required to control the reservoir design flood.

48. Deviations from the fixed operation schedule will normally be made by the Regulation and Meteorology Section of the District Office. Should communications fail, an engineer dispatched from the District Office will assume responsibility for deviation from the fixed schedule. Although the maximum scheduled release (7,000 cubic feet per second) is relatively small, it should not be throttled or stopped for more than
a few hours, and then only if extreme emergency exists downstream. Once the emergency has passed, the gates should be opened slowly to conform to the fixed schedule.

49. Examples of regulation.--The results of routing the 1937 winter flood, the reservoir design flood, and the spillway design flood through Alamo Reservoir, using the design flood control operation plan and assuming net storage available, are described in the following subparagraphs:

a. 1937 flood routing.--The flood of 7-10 February 1937 had the maximum peak and mean daily discharges of any flood for which there are actual gaging records. This flood was routed through the reservoir, assuming that storage space above elevation 1160.4, top of conservation pool, was available at the beginning of the routing. The 4-day inflow volume of 140,000 acre-feet was easily contained in the flood-control pool. The peak inflow of 92,500 cubic feet per second was reduced to an outflow of 7,000 cubic feet per second, and a maximum water-surface elevation of 1187.8 was reached.

b. Reservoir design flood routing.--In routing the reservoir design flood it was also assumed that, at the beginning of the flood, storage space would be available above elevation 1160.4. The peak inflow of 317,000 cubic feet per second was reduced to an outflow of a 7,000 cubic feet per second, and maximum water-surface elevation of 1215.2 was reached (see pl. 18).

c. Spillway design flood routing.--In routing the spillway design flood, which is based on a tropical storm, the conservative assumption was made that the flood would start five days after a summer flood of standard-project magnitude. At the start of the spillway design flood routing, the reservoir water surface was assumed at elevation 1200.

The peak inflow of 580,000 cubic feet per second was reduced to an outflow of 50,660 cubic feet per second, and a maximum water-surface elevation of 1259.6 was reached (see pl. 19).

## ORGANIZATION FOR OPERATION

50. Responsibility for operation.--The hydraulic and physical operation of Alamo Dam is the responsibility of the Chief, Construction Division. He has delegated authority for these functions through the Chief, Operations Branch, to the Chief, Regulation and Meteorology Section, and Chief, Maintenance Section, respectively. The Chief, Regulation and Meteorology Section is assisted in fulfilling his responsibility by the Section's Radio Unit, Meteorology Unit, Reservoir Regulation Unit, and Hydrography Unit. The Chief, Radio Unit, is responsible for maintaining reliable communications between the Los Angeles District Office and Alamo Dam, and for keeping radio equipment operable in the Alamo area. The Chief, Meteorology Unit is responsible for collecting and disseminating all weather data for the Bill Williams River area. The Chief, Reservoir Regulation Unit, is responsible for collecting hydraulic data and transmitting operational instructions to the Alamo Dam operator. The Chief, Hydrography Unit, is responsible for collecting rainfall and runoff data, maintaining records of reservoir operations, and installing and servicing hydrographic and meteorological instruments required for operation of the dam.

51. During flood emergencies, the normal hydraulic operations organization is greatly expanded and supplemented by other District employees who have been trained in their respective flood emergency duties. The basic organization and telephone numbers of key personnel effecting hydraulic operations during floods in the Bill Williams River area are shown in the District's "Natural Disaster Activities" memorandum. A Hydraulic Operations Center is established in the District Office under supervision of the Chief, Regulation and Meteorology Section to supervise the operations of a Radio Communications Group, Meteorology Group, Control Group, and Hydrography Group. The Radio Communications Group maintains communications with Alamo Dam and any radio units supporting flood operations, and monitors radio signals to check on reception. The Meteorology Group prepares precipitation forecasts for the dam and drainage area, and specialized flood-control weather forecasts as required. The Control Group contains a Flood Prediction Unit for forecasting flood flows at critical points in the Bill Williams River drainage and plotting hydraulic and hydrologic data, a Dam Operations Unit to supervise operation of the dam, and a Communications Unit to receive data and transmit operating instructions. The Hydrography Group, whose prime responsibility is obtaining hydrographic data during flood emergencies, operates a Telemark Unit to compute and post discharges from

field data. Additional information on organization and personnel assignments during flood emergencies is given in the District's "Natural Disaster Activities" memorandum.

52. The Chief, Maintenance Section is responsible for (a) safeguarding the project, (b) maintaining the project in good working condition, (c) operating hydrologic and hydraulic equipment, (d) making routine tests of equipment, (e) maintaining records as prescribed by the Regulation and Meteorology Section, and (f) keeping aware of information contained in the Reservoir Regulation Manual for Alamo Reservoir.

53. Instructions to dam operators.--The dam operators at Alamo Reservoir are required to:

a. Be present at the dam when rainfall or runoff is occurring.

b. Furnish the Regulation and Meteorology Section at the District Office a phone number through which they can be reached, whenever an assistant is not on duty.

c. See that all equipment at the reservoir, including recorders, indicating gages, gate mechanisms, power units, radios, etc., is in good condition.

d. Operate gates in accordance with instructions from the Regulation and Meteorology Section.

e. Keep the Regulation and Meteorology Section notified of any unusual developments such as trash accumulation, power failure, mechanical difficulties, etc.

f. Follow the fixed gate-operation schedule posted in the control house during lack of communication with the District Office or in the absence of a representative from the office.

g. Assist in every possible way engineers dispatched by the District Office during flood emergencies.

h. Maintain routine records, including water-surface elevations, outflow gage heights, precipitation amounts, gate openings, and daily log, on prescribed forms.

i. Notify local authorities and interested agencies of anticipated reservoir releases upon request of the Regulation and Meteorology Section or if communications with the District Office are broken.

## COLLECTION OF HYDROLOGIC DATA

54. Hydrologic facilities.--Sites of precipitation and stream gaging stations from which hydrologic information is collected for use in operating Alamo Dam are shown on plate 1. Radio-reporting rain gages are located: (a) at Bagdad Airport; (b) 6 miles north-northeast of Skull Valley; (c) at Perner Ranch; and (d) 19 miles north-northwest of Wikieup. There is also a glass tube rain gage in the control house, and a weekly rainfall recorder near the administration building.

55. Three stream-gaging stations and a venturi meter designed to record reservoir inflow and outflow are described in the following subparagraphs:

a. There are two inflow gaging stations in the basin. Neither of these stations, Big Sandy River near Wikieup (located 19 miles upstream) nor Santa Maria River near Bagdad (18 miles upstream) at present re
ports by radio; however, radio-reporting installations are proposed. These stations are each equipped with an instrument shelter, Stevens water-level recorder, staff gage, and cable car installation.

b. The outflow gaging station, Bill Williams River below Alamo Dam, is equipped with a shelter housing a bubbler system, Stevens waterlevel recorder, and radio. It is located on the left bank about 2,000 feet below the dam, adjacent to a control section of grouted rock, wire-mesh reinforced, and has a cable car installation. A rating curve based on observed and extrapolated discharges is shown on plate 20.

c. Flows through the low-flow bypass pipe around Gate No. 3 are measured by a venturi meter. The meter readings are transmitted to a recorder in the control house.

56. Adjustable staff gages are installed on the upstream face of the dam. There are 55 five-foot vertical sections marked in tenths of a foot. Selsyn-operated dial indicators and recorders for each control gate are located in the control house.

57. Reservoir water-surface elevations are obtained from a bubbler gage system consisting of a servomanometer, communication tubes, and a gas supply. Four tubes buried in the upstream face of the dam run from the servomanometer to orifices at elevations 990, 1,000, 1,057, and 1,140 feet. The servomanometer, located in the control house, operates a Stevens water level recorder and a dial indicator.

58. Communication facilities.--Communication facilities include four single-sideband AM transceivers; one in the administration building, one in the control house, and two in pickup trucks. These transceivers, operating on 2.350 and 6.785 mhz, provide communication between base and mobile units and the District Office. The call sign for the radio

station at Alamo Dam, a unit in the District's Flood-Control Net, is WUK 437, while call signs WUM 3020 and WUM 3021 are used by the pickup trucks. Emergency power for radio is supplied by a 4kw, 117-volt generator in the generator house. Single (lower) sideband transceivers operating on a carrier frequency of 6.785 mhz are installed in the District's Flood Control Center and in the Boulder City office of the Bureau of Reclamation. They are used to exchange information on operations at Alamo Dam and Lower Colorado River projects. Commercial telephone service is available in the administration building, dam operators' residences, elevator, and control house.

59. Hydrologic reporting network.--This network comprises: (1) an FM radio transceiver (base station) in the control house, operating on assigned frequencies of 169.425 and 171.875 mhz; (2) four precipitation reporting radio stations; (3) one stream-flow reporting radio station; (4) an FM repeater station on Mohon Peak to relay precipitation reports to the dam; and (5) a high speed teletypewriter in the control house, which automatically records hydrologic data transmitted by radio to the dam.

60. Weather forecasts.--The Regulation and Meteorology Section in the District Office receives daily forecasts for Arizona by teletype from the United States Weather Bureau office in Los Angeles. The forecasts are of two types: one gives general coverage of the State; the other is prepared specifically for flood control use, and contains predictions of precipitation amounts.

61. A facsimile weather chart recorder, connected to the National Facsimile Network, is located in the Regulation and Meteorology Section to supplement the written forecasts of the Weather Bureau for the area. The following information has been selected for reception from the large volume of weather data transmitted over the network:(a) current and prognostic surface and upper air charts, (b) maximum and minimum temperatures, (c) observed and forecasted 24-hour precipitation amounts, (d) observed snow depth, (e) 12-hour pressure changes, (f) a composite chart showing stability index, precipitable water, freezing level, and relative humidity, and (g) a weather satellite mosaic showing cloud cover over western North America and the adjoining ocean. The District meteorologist analyzes this information and issues special forecasts as required.

62. Operation record.--The operation record for Alamo Reservoir is maintained in the Regulation and Meteorology Section files. A record of operation is submitted to the Division Engineer and to the Chief of Engineers each month, using the form shown on plate 21. This record is submitted by the 15th of the month and contains data for the preceding month.

63. Operation reports.--The dam operator reports to the Regulation and Meteorology Section by radio at 0830 hours MST each workday. During storms he reports more frequently, as requested by that Section. He records operational data on plate 22 *(SPL* 19) and rainfall data at the dam on plate 23 (SPL 31). Originals of these reports are forwarded to the Regulation and Meteorology Section immediately following the end of the month. The data reported are tabulated on plate 24 *(SPL* 424) and transferred to the form shown on plate 25 *(SPL* 30) for computing necessary information. Precipitation reports for stations in the vicinity of the dam and drainage area are received daily or more often from the field by radio. Reports are obtained at approximately 0830 hours MST each workday and more often during storms. They are entered on the form shown on plate 26 (SPL 277).

## COORDINATION WITH OTHER AGENCIES

64. A list of agencies, together with a brief explanation of their relationship to the operation of Alamo Reservoir, is given in the following subparagraphs:

a. U.S. Bureau of Reclamation.--The Bureau of Reclamation operates Parker Dam, and controls the elevation of Havasu Lake located at the confluence of the Bill Williams and Colorado Rivers. The Bureau is responsible for operation of the lower Colorado River system and for flood protective work on the main stem of the river. Hydrologic and hydraulic data are exchanged by radio between the Bureau's Boulder City office and the Corps'control center in the Los Angeles District Office. This information includes reservoir data and precipitation reports, as well as discharges along the lower Colorado River and outflow from Alamo Dam.

b. U.S. Weather Bureau Airport Station, Phoenix, Arizona.--The Weather Bureau office at Phoenix is the River District office for the Colorado River and tributaries from the Colorado River above the mouth of the San Juan River to the Arizona-Mexico border. Flood conditions, weather forecasts, and precipitation reports for the Bill Williams River area may be obtained by the Los Angeles District on request, and relayed by radio or telephone to Alamo Dam.

c. U.S. Geological Survey, District Office, Tucson, Arizona.--By agreement between the Corps of Engineers and the U.S. Geological Survey, the latter organization services the two stream gaging stations in the basin and the outflow gaging station below Alamo Dam. They also take discharge measurements. Streamflow records are maintained by the District office at Tucson, Arizona, and are published in the annual "Water Supply Papers."

d. U.S. International Boundary and Water Commission, El Paso, Texas.--The International Boundary and Water Commission is interested in the operation of Alamo Dam because of the Commissions responsibilities relating to the 1944 Water Treaty with Mexico.

e. Arizona State Parks Board, Phoenix, Arizona.--The Arizona State Parks Board is recreational licensee for Alamo Reservoir.

f. Arizona Game and Fish Department, Phoenix, Arizona.--The Arizona Game and Fish Department is licensee for all fish and wildlife areas at Alamo Reservoir.

## RESERVOIR FILLING FREQUENCY

65. A filling frequency curve for Alamo Reservoir is shown on plate 27. In deriving this curve, the shape of the average inflow hydrograph for 11 floods in the Bill Williams River at the Alamo Dam site was determined. Peak flows for various frequencies were taken from plate 7 of General Design Memorandum No. 3, Alamo Reservoir. Using these peak inflows, hour-by-hour average flows were computed for floods of various frequencies. These were routed through the reservoir, starting at the top of the recreational pool, and using the flood-control operation plan shown in table 11 and gross capacity.

## RECREATIONAL DEVELOPMENT OF RESERVOIR AREA

66. Recreational development.--Public access development is described in General Design Memorandum No. 1, Alamo Reservoir, December 1961. The following subparagraphs cover the facilities initially provided:

a. Alamo Recreational and Administrative Area.--Facilities include an administration and service building, with offices for public-access development. Additional public facilities now or eventually will include camping and picnic areas, restrooms, parking facilities, amphitheater, restaurant, store, riding stable, and a service station.

b. Bill Williams Overlook Area.--The Bill Williams Overlook Area, located a half-mile upstream from the dam, is near the Alamo Reservoir Recreational and Administration Area. Initial development provides an observation building, parking, and sanitary facilities.

c. Alamo Reservoir Recreational Pool.--The water-surface area of the recreational pool is about 556 acres. Recreational facilities include areas for swimming, boat-launching, fishing, and water sports.

d. Ocotillo Game Management Area.--An area is provided for hunting migratory wild fowl and other game in the vicinity of the recreational pool, complete with service and administration building and restroom facilities. Other improvements will include parking facilities for 200 cars and trailers, a floating boat dock, and boat launching ramps. A road will be constructed from the Ocotillo Area to the Alamo Reservoir Recreational and Administration Area. Plate 28 shows the recreational layout for Alamo Reservoir and vicinity.

## STUDIES IN PROGRESS OR PLANNED

67. It is proposed to review the study establishing a recreational pool elevation which would provide carryover storage during dry years to compensate for water lost through percolation, evaporation, and water rights releases. With the accumulation of experience, some adjustment in the gate operation schedule may be advisable.